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A STUDY OF DELAYED GERMINATION IN ECONOMIC
SEEDS

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY 204

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(WITH ONE FIGURE)

This paper presents the results of an attempt to discover some of the practical problems that seedsmen and growers have to meet, and to work out, so far as possible, practical methods of solving these problems. The seeds tested were furnished by six of the leading seed houses of the United States.

In the present state of our knowledge it can be said that delayed germination and poor germination are due to one or more of the following causes: hard-coatedness, the need of after-ripening, exclusion of oxygen by the seed coat, the effect of frost on seeds, fungi on or in seeds, and of course the presence of seeds containing dead embryos.

Hard-coatedness

The condition of hard-coatedness in the seeds of legumes is well known. To overcome this condition investigators have used hot water, chemicals, and mechanical devices for scratching or puncturing the seed coat.

The use of hot water for forcing germination is undoubtedly older than the references to it in periodical literature. It was recommended by BRUYNING (6) in 1893 for seeds of *Ulex europaeus*,

and by WERNICKE (30) in 1895 for several different kinds of seeds. Mention may also be made of the work of JARZYMOWSKI (17) in 1905 with seeds of various economic legumes, and of BOLLEY (3) in 1912 with those of alfalfa. BOLLEY obtained positive improvement in germination if exposure to a given temperature was not long enough to kill the embryo.

Treatment with concentrated sulphuric acid dates from the work of ROSTRUP (25) in 1896-1897. It was also used by TODARO (29) in 1901, by HILTNER (14) in 1902, by JARZYMOWSKI (17) in 1905, and by BOLLEY (3), and LOVE and LEIGHTY (22) eight years later. Increased germination was obtained in all these cases.

Treatment with other chemicals has included the use of ether, ethyl, and other alcohols (VERSCHAFFELT 31, 1912), chloroform, sodium hydroxide, postassium hydroxide, potassium nitrate, and mercuric chloride. Of these, the lower alcohols are the only ones that are very effective.

There are obvious practical objections, however, to the use of either hot water or chemicals. As a consequence, there have been numerous efforts to devise means for the mechanical treatment of hard-coated seeds. In Germany, KUNTZE and HUSS (16), working about 1890, were able with a scratching machine to increase the germination of *Lathyrus sylvestris* 83 per cent, *Vicia Cracca* 71 per cent, and *Astragalus Glycyphyllos* 77 per cent.

Somewhat later MICHALOWSKI devised an apparatus in which the seeds were passed between two rollers, one of rubber, the other of rough steel. Smaller sorts of seeds were badly crushed by such a mechanism, and it was later displaced by two others, one designed by the Wissinger Seed Co., of Berlin, the other, called a "preparator," by H. NILSSON of the experiment station at Svalöf, Sweden. In both of these the seeds are thrown from a revolving disk against the concave surface of a circular rough stone, within which the disk revolves. HUME and GARVER (15), using the "preparator," obtained a definite increase in the germination of seeds of *Medicago sativa*, *M. media*, and *M. falcata*. Another machine now in use in England has made it possible, according to CARRUTHERS (7), the designer, to buy clover seed guaranteed to germinate 98-100 per cent. The seeds to be treated are fed into a revolving cylinder

lined with sharp, close-set steel points against which the seeds are thrown and scratched as the cylinder revolves.

Mention should be made here also of an apparatus invented by KÜHLE (19) for scraping the rough outer covering from sugar beet "seed." Very satisfactory results have been obtained by its use, since "seeds" so treated absorb water better than untreated ones, and germinate more rapidly; they also give a better total germination, on account of the removal of fungus-infected material from the outside of the "seed," especially if this removal is followed by treatment with some fungicide.

With any one of the machines here described except the last, which serves a slightly different purpose, it has been found difficult to treat every seed that passes through and, at the same time, to avoid serious cracking of the coat or bruising of the entire seed (GLOCKENTOEGER 11).

It is believed that these difficulties have been avoided in a machine devised and in use during the winter of 1912-1913 at the Hull Botanical Laboratory of the University of Chicago. This machine consists of a direct pressure blower, furnished by the Connersville Blower Co., to which is attached an apparatus through which seeds can be fed and blown against the points of a bank of needles. In experiments conducted with this machine, the blower was driven by a two horse-power motor and gave pressures as high as 2.5 pounds to the square inch. The needles used were of three sizes, nos. 4 and 11 sewing needles and no. 4 darning needles, made up into three different cylindrical bunches or banks, each bank of course consisting of only one size of needles. The needles were held together by solder at the eye end and by wire or a ferrule one-half to two-thirds of the distance from the eye to the point.

In the cut here shown (fig. 1) the needles are about half an inch from the end of the air tube. In practice a screen cap is placed over the needles and the tube as a covering for a glass jar beneath, into which the seeds fall. To use the apparatus, valve *e* is closed and valve *b* is opened; seeds are poured into compartment *c*; valve *b* is closed and the blower started; valve *e* is then opened wide enough to let the seeds out, but not so wide that they interfere with each other as they strike the needle points. It is

plain that the distance the valve is to be opened will vary with different seeds, but will not be at any time particularly hard to determine. With valve *b* closed, there was no difficulty in getting the seeds down into the air tube; with it open they would be blown out at *d*.

The opening at *h* is five-eighths of an inch in diameter and will accommodate seeds of sweet peas, lupines, *Lathyrus*, honey locust,

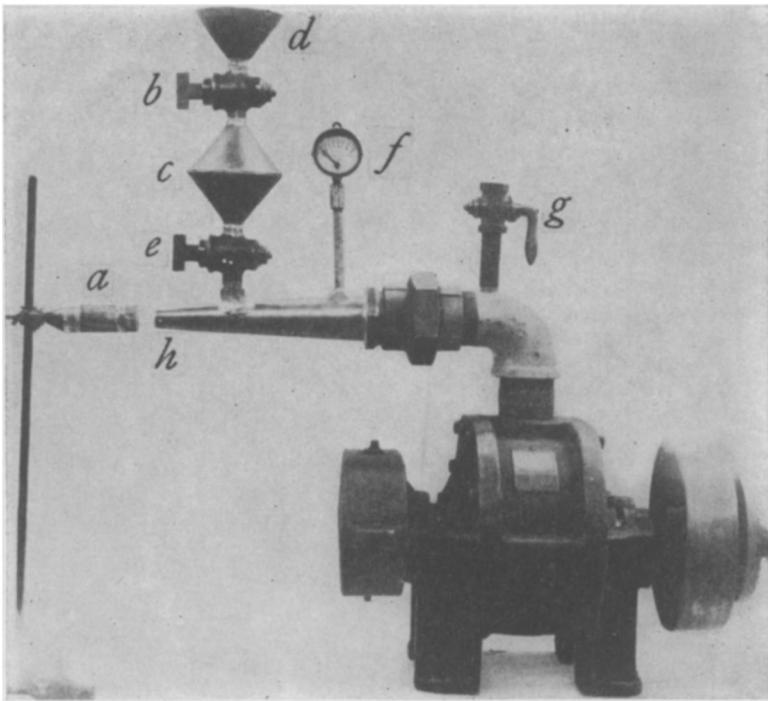


FIG. 1.—Apparatus for increasing the germination of hard-coated seeds by blowing them against a bank of needle points.

etc. When smaller seeds are to be treated, an attachment with three-eighths inch feed, valves, and air tube can be adjusted readily. Valve *g* can be used to regulate the pressure, as read on the pressure gauge *f*.

Tests were made of treated and untreated seeds, on filter paper kept moist with distilled water, at a temperature of 23–25° C. The results are summarized in table I.

It is plain that treatment with the machine increased germination considerably in the case not only of legumes, but also of snapdragon, *Delphinium*, sweet marjoram, *Ipomoea*, okra, and lettuce.

TABLE I
GERMINATION OF SEED TREATED WITH MACHINE

KIND OF SEED	DURATION OF TEST IN DAYS	GERMINATION	
		Untreated	Treated
Alfalfa.....	10	51	99
Alfalfa.....	10	74	94
Bossiae heterophylla.....	30	3	73
Bossiae scolopendria.....	30	11	52
Cianthus Dampieri.....	10	0	80
White clover.....	10	70	94
Delphinium chinense.....	30	74	96
Dillwynia ericifolia.....	30	2	77
Gleditschia.....	90	0	70
Ipomoea (average of 3 spp.).....	10	34	71
Lathyrus (average of 3 vars.).....	14	63	93
Lettuce (average of 11 vars.).....	12	55	83
Sweet marjoram.....	30	54	96
Mustard (average of 2 vars.).....	14	20	69
Okra.....	30	34	79
Perennial peas (average of 2 vars.).....	10	62	87
Sweet peas (average of 5 vars.).....	14	70	99
Platylobium trilobatum.....	30	13	64
Snapdragon.....	30	6	23
Vetch.....	10	77	92
Average.....		40.7	83.7
Increase due to treatment.....			43.7

It is not strictly correct, however, to call lettuce seeds hard-coated. That their germination is improved by treatment with the machine shows delay to be due to coat restrictions. The coat restrictions are removed also by soaking in water for 24 hours, hence it is likely that delay is caused by a reduction in rate of water absorption rather than by lack of oxygen. Whatever be the character of the seed coat, or coats, which interferes with germination, it disappears as the seed grows older. These points are well illustrated by table II. The data here presented support the statement made by various seedsmen, that two or three-year-old lettuce seed gives better germination than fresh. How this condition comes about is not known, but it probably depends on

changes in the permeability of the seed coat. It is certainly not a matter of embryo changes.

TABLE II
GERMINATION OF TREATED AND UNTREATED LETTUCE SEED

VARIETY	DURATION OF TEST IN DAYS	GERMINATION		
		Untreated	Treated with machine	Soaked in H ₂ O 24 hrs.
Black-seeded butter—				
1909.....	12	98	.....	.....
1910.....	12	99	.....	.....
1911.....	12	89	93	95
1912.....	12	67	97	100
Prize head—				
1909.....	12	98	.....	.....
1910.....	12	97	.....	.....
1911.....	12	84	96	97
1912.....	12	76	98	96

It appears, from a study of the records kept in this work, that not only the total germination, but also the rapidity or energy of germination is greater in treated than in untreated seeds. This is shown in table III.

TABLE III
RAPIDITY OF GERMINATION OF TREATED AND UNTREATED SEEDS*

Kind of seed	Germination after	Untreated	Treated
Alfalfa.....	3 days	48	98
White clover.....	3 "	69	89
Perennial peas.....	4 "	0	33
Perennial peas.....	4 "	24	80
Lupines.....	4 "	40	88
Delphinium.....	5 "	4	44
Sweet peas.....	4 "	0	70
Sweet peas.....	4 "	16	86

* For final germination percentage of these samples see table I.

Such rapidity of germination would clearly be of advantage in making the crop uniform in size and age, and in keeping down weeds. Indeed, it may be said truly that vigor of germination and vigor of the plants produced are more important than merely high germination percentage. Plants that get a good strong start

are more certain to be productive than those that for any reason are weak from the beginning.

Before this machine can become commercially practicable, experiments must be conducted to determine: (1) the possibility of substituting something else for needle points; (2) the proper distance these points should be from each other to give the best results for different sized seeds; (3) the pressure necessary to give the best germination for different kinds of seeds; for certain legumes a pressure of two to three pounds is necessary, for lettuce one pound or even less; (4) the effect of storage on the germination of treated seeds; (5) the germination of treated seeds in soil. To be effective in overcoming hard-coatedness, the needle point need only pass through the palisade layer and not entirely through the coat. Even with this slight deformation it is possible that bacteria and fungi can gain an entrance. That destruction by bacteria and fungi actually does take place was shown by JARZYMOWSKI (17) for seeds of *Ulex europaea*, lupines, and other large-seeded legumes which had been treated with the Wissinger machine. Red clover and *Lotus corniculatus* were the only ones whose germination in soil after treatment was not seriously reduced.

As to the germination in soil of seeds treated by the blowing method here described, there are not at present enough data on hand to justify the drawing of definite conclusions. Preliminary experiments seem to indicate for alfalfa seed, where the percentage of hard seed is high, that germination in soil is definitely better after treatment than before. Further investigation, of course, is necessary before this can be confirmed. In conclusion it may be stated that there was no serious crushing or cracking of seeds or seed coats by this machine.

The need of after-ripening

This is a condition which occurs, to mention only a few cases, in seeds of *Crataegus*, various conifers, *Fraxinus*, potato tubers, and lily-of-the-valley bulbs. For a discussion of the general situation and a résumé of the literature the reader is referred to the paper by ECKERSON (10) dealing with after-ripening in the seeds of *Crataegus*. The work to be discussed here had to do with the

germination of seeds of conifers, and specific reference will be made to a few of the more pertinent papers on the subject.

It is a matter of common knowledge that conifer seeds germinate slowly. It is also well known for several of them that as they grow older the rapidity of germination increases, up to at least the end of the first 6 months after they were gathered. SCHWAPPACH (27) states that in the fall seeds of *Abies* did not begin to show sprouts for 60 days, and required 40 days more before the test could be considered closed. In March they began almost immediately and finished in 20 days. The conclusion is natural that after-ripening takes place, and this, in fact, is assumed by workers who have recently attacked the problem. HILTNER and KINZEL (14), it is true, reasoning from results obtained by treating seeds of *Pinus Strobus*, *P. Peuce*, and *P. Cembra* with concentrated sulphuric acid, ascribed the delay to coat restrictions. LAKON (20) has made the objection that the tests on which these authors rely were too few and on too small a number of seeds. He repeated their experiments with the same three species of pine, but could obtain no forcing of germination. Untreated seeds took up water just as well as did the treated ones, even though their outer coats were hard. Careful determinations of the amount of water absorbed by untreated seeds of *Pinus sylvestris*, *P. Strobus*, *P. Peuce*, and *P. Cembra* showed that all of them reached nearly the maximum in 24–48 hours. Increases in weight after that time were practically negligible; hence it is clear that such seeds cannot be considered "hard-coated" like the seeds of legumes. Moreover, the cutting test, applied to these seeds, showed that all of them were damp, that is, had absorbed water. Increases in weight, therefore, were not due to a few easily swelling seeds. From these results LAKON concludes that conifer seeds are not, strictly speaking, "hard-coated," and that delay is due to conditions within the embryo.

Although LAKON found concentrated sulphuric acid ineffective, CORREVON states, in a paper published somewhat earlier, that weak acid (0.25 per cent acetic or 2 per cent phosphoric) increases the germination of seeds of *Juniperus Cedrus*.

SCHWAPPACH recommends cold storage for 14–30 days (he does not say how cold) for seeds of *Pinus Strobus*, followed by a germi-

nation temperature of 25° C. The common practice of layering various conifer seeds doubtless finds its justification in a shortening of the time required for germination. Low temperatures have also been used for preserving the vitality of conifer seeds. HAACK (12) dried seeds so they lost about 2 per cent in weight, then stored them in dry, air-tight containers on ice. CLEMENS (9) stored seeds in the refrigerator of a brewery in vessels containing sodium carbonate to absorb moisture and carbonic acid. Both investigators report that seeds thus stored remained viable longer than those kept under ordinary laboratory conditions.

In order to analyze the situation more carefully, the following series of experiments were conducted on seeds of various conifers.

1. Tests of untreated seeds.

2. Tests of seeds which had been in cold storage (3–5° C.):

(a) in wet sand, (b) in weak solutions of hydrochloric acid, (c) in distilled water.

3. Tests were made with seeds which had been injected with weak hydrochloric acid or with water, by exhausting the air from them when they were in these liquids, and then restoring the pressure to normal. This was repeated at least three times for all seeds here spoken of as injected. Table IV summarizes the results obtained in series 1 and 2a.

TABLE IV

GERMINATION OF CONIFER SEEDS, UNTREATED AND AFTER STORAGE IN WET SAND
AT 3–5° C.; PERCENTAGE GERMINATING AFTER ONE MONTH IN GERMINATOR

KIND OF SEED	DRY STORAGE UNTREATED				COLD WET STORAGE FOR			
					1 month	2 months	3 months	4 months
	Date of starting germination							
	Jan. 26	April 4	April 24	May 30	Feb. 26	Mar. 23	April 26	May 28
Cupressus macrocarpa	8	0	1	.....	15	27	40	36
Picea Menziesii	56	42	.....	23	70	60	.....	.....
Pinus austriaca	57	48	27	28	78	88	.....	64
Pinus Strobus	12	10	6	28	34	40	44	59

The results given in the table show that germination was definitely increased by cold wet storage for four kinds of conifers.

In no case does the maximum germination of seeds of a given kind from dry storage equal that of seeds of the same kind from cold wet storage. The effect of the cold wet storage is most noticeable in the cases of *Pinus Strobus* and *Cupressus macrocarpa*, where increases of 32 per cent and 31 per cent respectively were obtained. For all of the seeds here reported on, except those of *Pinus Strobus*, dry storage seemed to cause a decrease in viability. This can be seen from the first four columns of the table. Tests of *Pinus Strobus* were run for 60 days, the other three for 30 days.

TABLE V

GERMINATION OF SEEDS OF CONIFERS AFTER SOAKING IN WEAK ACID AND STORAGE AT 3-5° C.

KIND OF SEED AND LENGTH OF TIME IN COLD STORAGE	CONTROL	ACID (HCl)				WATER	
		Soaked			Injected		Soaked
		n/20,000	n/10,000	n/6,400	n/20,000	n/6,400	
<i>Pinus Strobus</i> —							
3 days		44	58	53	66	54	.....
6 " 		51	57	44	.....	.....	.....
10 " 		53	65	67	.....	.....	63
No cold storage	30	.....	.....	.....	.....	.....	50
<i>Pinus austriaca</i> —							68
3 days		64	.....	52	.....	.....	65
6 " 		48	.....	42	.....	.....	59
10 " 		35	.....	50	.....	.....	45
No cold storage	52	54	.....	.....	.....	.....	.....

The series of experiments shown in Table V was planned to determine whether delay in germination is due to an alkaline or neutral reaction of the embryo. It was thought that if such is the case, weak acid solutions would change the reaction sufficiently to cause growth to begin, when the seeds were placed in the proper conditions.

The results obtained for *Pinus Strobus* do not, however, bear out this theory. Seeds injected with distilled water gave 18 per cent better germination than those merely soaked in it, and slightly better than those injected with weak hydrochloric acid. It seems likely from this that delay is due merely to lack of water. When

this water was supplied, by long soaking or by forcible injection under pressure, germination was much improved.

Results for *Pinus austriaca* are less conclusive on this point. They do show, however, and the same is true for *P. Strobus*, that soaking in either water or weak acid gave greater germination than was obtained in the controls, 38 per cent and 13 per cent respectively. For *P. austriaca*, better results were obtained from short than from long soaking.

Referring again to table IV, it is possible that the increases in germination shown there were due not so much to the cold storage in itself as to the thorough infiltration of the seeds with water. There is need of much more work on this question before any definite conclusions can be drawn.

Exclusion of oxygen

No attempt will be made to review former work, since this has already been done by SHULL (28). Results presented in table VI seem to indicate that the germination of certain economic seeds is delayed for lack of oxygen. They also indicate the need of a detailed study of these seeds.

TABLE VI
GERMINATION OF SEEDS TREATED WITH OXYGEN OR HYDROGEN PEROXIDE

Kind of seed	Duration of test in days	Untreated	In 80 per cent oxygen	In 0.15 per cent H ₂ O ₂
Dandelion.....	14	56	.....	72
Datura—				
Golden Queen.....	14	73	.....	70
Wrightii.....	14	20	.....	100
Lettuce—				
Grand Rapids.....	10	0	44	32
Martynia.....	20	0	90	80

Datura Wrightii was forced considerably by hydrogen peroxide, *Datura Golden Queen* not at all. Lettuce gave good results, but, as has been suggested, this is probably due to absorption of water.

Effect of frost on seeds

ATTERBERG (2) says that seeds of oats and barley harvested in Sweden after a heavy frost gave fair to good germination in the

laboratory, but in many cases no plants when sown in the field. Unpublished data obtained by EASTHAM in Canada show that the germination of oats grown in the prairie provinces is often seriously reduced by early frosts. He says, "as far as our observations go, a couple of degrees of frost in the milk stage are in many instances sufficient to ruin oats for seed. In the dough stage they are not nearly so susceptible, and when well ripened and dry stand considerable frost without serious injury." EASTHAM found also that such seed, germinating poorly when harvested, often improved with age. This seems to indicate in such cases the necessity for a period of after-ripening. Through the courtesy of the Canadian seed laboratory and two American seed houses the author has had the privilege of testing several samples of frosted oats. The results are summarized in table VII.

TABLE VII
GERMINATION OF OATS

VARIETY	UNTREATED; ON FILTER PAPER AT 20° C.	UNTREATED; SENDER'S TEST 18°-20° C.	HULLS OFF; ON FILTER PAPER AT 20° C.	HULLS REMOVED; ON COTTON IN PETRI DISHES AT 22° C.			
				80 per cent oxygen	60 per cent oxygen	40 per cent oxygen	20 per cent oxygen
Lincoln .	85	40	79	.....	.....	.....	.....
Swedish .	77	40	80	.....	.....	.....	.....
4920	34	35	38	31	25	38	33
5139	46	.....	.....	.....	.....	.....	.....
3477	56	43	.....	.....	.....	.....	.....
3974	45	42	.....	.....	.....	.....	.....
4948	89	62	94	93	97	95	96
5302	16	27	.....	.....	.....	.....	.....

The best germination was obtained from hulled seeds in oxygen, though the results are more clear-cut for no. 4948 than for no. 4920. No definite conclusions can be drawn as to what percentage of oxygen is most effective. It is noteworthy that two samples, nos. 3477 and 4948, show much better germination, 23 and 27 per cent respectively, than they did when tested in the Canadian Seed Laboratory six months earlier. This agrees well with the statement made above that frosted oats go through a process of after-ripening and improve in viability as they grow older. There is the same need of after-ripening in wild oats (*Avena fatua*), as has been

shown by Atwood. But referring to the table again, it will be seen that one sample, no. 5302, deteriorated in vigor as it grew older, since it gave a percentage of 27 when first tested and 11 per cent less 6 months afterward. Considering the results as a whole, it is clear that frosted oats are unreliable in performance and of very doubtful value for seeding purposes.

Another crop which sometimes suffers from frost is garden peas. Within the last two or three years the growing of garden peas for seed has become an important industry in Idaho and Montana. It has been found that certain of the late varieties grown there are injured by frost and the viability of the seed seriously impaired.

A study of 14 samples of such peas has shown that decrease in germination is probably due to two different causes, both of which, however, may be the effect of frost.

1. Actual injury to the embryo, especially the tip of the radicle. It has a whitish shriveled appearance and starts to grow very slowly, if at all.

TABLE VIII
GERMINATION OF PEAS

Variety	Coats on; 25°	Coats on; 25°	Coats off; 20°
Premium Gem.....	90	82	86
Nott's Excelsior 73186.....	68	.....	.....
" " 71531.....	98	100	.....
Telephone 885H.....	58	46	55
Gradus 913K.....	44	36	58
" 913S.....	70	.....	76
Dwarf Defiance 874C.....	56	.....	52
" " 874K.....	64	.....	96
" " 874H.....	78	.....	76
Alderman 912S.....	66	.....	.....
" 912K.....	82	.....	96
" 912T.....	56	.....	.....
" 912V.....	78	.....	92
Telegraph 68528.....	48	.....	50
Average.....	67	.....	74

2. The presence of fungi on or in the seed coat. That this actually decreases germination was shown by the work summarized in table VIII. With the coats on, the seeds of all the samples here reported on showed much fungus infection; with coats off,

very little or even none at all. Ten samples gave an average germination of 67 per cent with the coats on, and 74 per cent with the coats off, a difference of 7 per cent. Individual samples, such as Dwarf Defiance 874K, gave even more striking results.

The condition of garden peas, with reference to fungi, is approached more or less closely by that of a large number of other garden and flower seeds as is shown in table IX, summarizing the general results of this investigation, and in the discussion following.

Plants whose seeds show delayed germination, classified according to probable causes (the word "probable" is used advisedly, for while the evidence is convincing in some cases, it is much less so in others):

1. Hard-coatedness.—*Canna*, *Cianthus Dampieri*, *Delphinium*, *Erythrina*, *Hibiscus*, *Ipomoea* (4 spp.), *Lathryus*, *Lupinus*, sweet peas (4 vars.), snapdragon, alfalfa, sweet clover, white clover, lettuce (10 vars.), mustard (2 vars.), okra, sensitive plant, sweet marjoram, vetch, *Gleditschia*.
2. Frosted.—Oats, peas (8 vars.).
3. Need of after-ripening.—Wild cucumber, *Picea* (3 spp.), *Pinus* (2 spp.).
4. Exclusion of oxygen by the seed coat.—*Datura Wrightii*, *Martynia*.
5. Cause of delay not determined.—*Coix Lachryma*, feather grass, Pampas grass, asparagus, barley, blue grass, cardoon, celery, chives, dill, horehound, kaffir corn, leek, millet, parsley, parsnip, pepper, radish, rosemary, spinach, summer savory, thyme, *Aquilegia*, *Asparagus Sprengeri*, *Bignonia*, *Centaurea*, *Clematis*, dandelion, *Datura Golden Queen*, *Eschscholzia*, foxglove, heliotrope, *Helianthus*, hop, lavender, *Momordica*, *Nasturtium*, *Oenothera*, pansy, *Pentstemon*, *Primula*, *Salvia*, *Verbena*, *Abies Mertensiana*, *A. pectinata*, *Berberis*, *Betula alba*, *Cupressus horizontalis*, *C. macrocarpa*, *C. pyramidalis*, *Larix*. Further work would doubtless explain the cause of delay in many of these seeds and make the growing of plants from them a much simpler matter than it now is.

Very pertinent at this point are the results from the Minnesota Seed Laboratory for 1910 and 1911 (OSWALD 23). Of field seeds 14 kinds were tested; of garden seeds 26 kinds. Of field seeds, for

TABLE IX
SHOWING THE NUMBER OF SPECIES AND VARIETIES TESTED, CLASSIFIED ACCORDING TO THE QUALITY OF GERMINATION AND THE PROBABLE CAUSES OF DELAY

3 of the kinds, 50 per cent or more of the samples were below the government standard of germination. Of garden seeds, for 16 of the 26 kinds, 50 per cent or more of the samples were below standard. Mention should be made also of work by BROWN (5) on the germination of packeted vegetable seeds. He found that the average germination of box vegetable seeds put up by 60 firms for four years was 60.5 per cent. The lowest average for any firm was 36.5 per cent, the highest 81.5 per cent. The average germination of packeted vegetable seeds put up by 20 mail-order houses in 1911 was 77.5 per cent (lowest average 76.2 per cent, highest 77.5 per cent). Just what these figures signify is not clear. There are three possibilities: (1) the seeds were poor because of the seedsman's dishonesty or carelessness; (2) the seeds were poor because it is not possible with present methods to produce better ones; if so, the government standard is, now at least, too high and methods of production need improvement; (3) the seeds seemed poor because present methods of making germination tests do not always adequately determine the value of a given sample. In the writer's opinion, the responsibility for low test must be shared about equally by all three, though the first is a less important factor than it was a few years ago.

6. Plants whose seeds were found infected with fungi.—Feather grass, asparagus, beggar weed, buckwheat, cardoon, celery, chives, sweet clover, dill, kaffir corn, leek, millet, oats, parsley, peas (12 vars.), pepper, radish, rosemary, spinach, thyme, vetch, *Aquilegia*, *Asparagus Sprengeri*, *Bignonia*, *Clematis*, *Cianthus Dampieri*, wild cucumber, dandelion, *Datura Golden Queen*, *D. Wrightii*, *Helianthus*, hop, *Ipomoea* (4 spp.), *Lathyrus*, lavender, *Nasturtium*, pansy, sweet peas (4 vars.), *Primula*, *Verbena*, *Abies Mertensiana*, *A. pectinata*, *Berberis*, *Cupressus horizontalis*, *C. macrocarpa*, *C. pyramidalis*, *Picea excelsa*, *P. Menziesii*, *P. rubra*, *Pinus austriaca*, *P. Strobus*.

The species and varieties tested were 134, but 30 of these are omitted from the second section of table IX; 29 of these germinated rapidly and well, and one other, on account of bad infection with fungi, showed not delayed but definitely poor germination; 69, or 51.4 per cent of the total, were found more or less infected with

fungi. This point was determined for each kind of seed not more than two days after the test began. All filter paper was boiled 5-10 minutes before being used and kept moist with distilled water during the test. Repeated washing of seeds and removal to fresh filter paper showed that in all cases infection came from the seeds, not from the paper.

There is no intention here of implying that seedsmen in general purposely put on the market seeds low in vitality or badly infected with fungi. It does seem clear, however, that there is need of closer supervision by the seedsmen themselves of all stages of the process of seed production; alternation of crops to avoid soil-infection, cultivation, harvesting, threshing, cleaning, storage; all of these need close attention if seed of the best quality is to be produced. The most candid way in which to approach the whole question is to admit that seed analysts, seed-growers, and seed merchants do not at present know a number of things they need to know in reference to the question of fungus infection of seeds, and to all the other questions considered in this paper. The whole matter constitutes an extremely complex physiological and pathological problem, with very practical aspects, the solution of which can be brought about only by careful study from several different points of view. To be specific, the following lines for investigation may be suggested:

1. The relation of germinator tests to the actual vegetation of seeds in the soil. This should be studied through a period of several years.

2. The relation of fungi on or inside of seeds to the germination of such seeds in soil. At the risk of seeming to repeat unnecessarily, the writer wishes to say that in his opinion the importance of this problem is only poorly appreciated in this country. Some recognition of the dangers accompanying fungus infection of seed has appeared of late in the work of BOLLEY and others in the United States, and in German agricultural literature. APPEL (1), writing on the relation of pathology to seed control, says that in seed-testing stations, pains should be taken to give judgment as to the presence of spores of plant diseases on seeds to be examined. It is his opinion, further, that in comparative field tests more

attention must be given than formerly to pathological phenomena. Observations on this point should be given along with other data from the experiment.

3. The causes of delayed germination in asters, certain hardy perennials, labiates, ornamental grasses, cucurbits, conifers, frosted oats, *Betula*, and *Berberis*.

4. The value of hard seeds of legumes when planted in the soil.

5. The relation of any or all of the causes of delayed germination to the vigor of the plants produced. It is not enough that a given lot of seeds shall be free from impurities; it is not even enough that it shall give a high germination percentage. It must, above all, give rise to vigorous productive plants, when planted in field conditions. Consequently, any knowledge which will teach us how to grow such seeds and how to know poor seeds is of the greatest practical importance.

Summary

1. Hard-coated seeds of legumes, and seeds of *Delphinium*, *Ipomoea*, lettuce, mustard, okra, sweet marjoram, and snapdragon can be forced to more rapid germination by being blown against needle points.

2. For two varieties of lettuce it is shown that the seed improves in viability as it grows older, up to the end of at least the fourth year. This improvement is probably due to increased permeability of the inner seed coat to water.

3. Cold storage in wet sand increased the germination seeds of *Pinus Strobus* by 32 per cent, of *Cupressus macrocarpa* by 31 per cent. Delayed germination of conifer seeds, more especially those of *Pinus Strobus* and *P. austriaca*, seems to be due to lack of water intake, and not to an alkaline or neutral reaction of the embryo. This statement is supported by the fact that seeds injected with distilled water gave better germination than those merely soaked in water or in weak acid at the temperature of melting ice. Any kind of soaking or injection gave 13–38 per cent better germination than was obtained with the controls.

4. Certain samples of frosted oats improve in germinating power as they grow older, others deteriorate.

5. Certain late varieties of western-grown garden peas germinate poorly. This is shown to be due to one or both of two causes: (a) actual frost injury to the embryo; (b) the presence of fungi on or in the seed coat or inside of it.

6. Seeds of 51.4 per cent of all species and varieties examined showed fungi on the seed coat within two days after being put to germinate.

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